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CENTRIFUGE TESTING OF A G COMPENSATED/PRESSURE DEMAND
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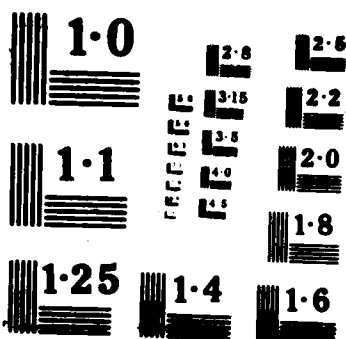
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CENTRIFUGE TESTING OF A G COMPENSATED/PRESSURE DEMAND OXYGEN REGULATOR

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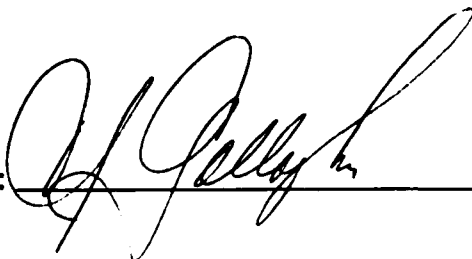
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Centrifuge Testing of a G Compensated/Pressure Demand Oxygen Regulator.

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ABSTRACT: Six subjects were exposed to unassisted positive pressure breathing at levels not exceeding 30 mmHg breathing pressure while riding on a centrifuge. Acceleration in the +Gz direction was applied as either a ramp or a plateau and conditions ranged from relaxed to unassisted positive pressure breathing with an anti-G suit. The purpose of this study was to evaluate the performance of a G compensated positive pressure breathing regulator with respect to stated output pressure versus +Gz level, the pressure control concept/schedule employed, and subject acceleration tolerance. The regulator was found to perform as stated given the pressure range of interest and the experimental conditions. The pressure control concept/schedule and acceleration tolerance were related factors. It was found that the subjects who rode to higher +Gz levels received higher levels of breathing pressure and in turn an increase in acceleration tolerance.

INTRODUCTION: The Navy is currently evaluating positive pressure breathing as an acceleration tolerance enhancement technique. Many factors must be considered with this technique such as unassisted versus assisted pressure breathing, pressurization schedule and its dependencies, and the applicability to the high G onset and endurance situations. The first phase of this effort was to evaluate a commercially available G-compensated positive pressure breathing regulator in the unassisted mode of pressure breathing. Past studies using unassisted positive pressure breathing (25-35 mmHg) have indicated increases in tolerance level and time (5)(4) but an insignificant difference in tolerance between this method and the M-1 maneuver(2). The study to be described marks the completion of the first phase of the evaluation effort.

METHOD: Six experienced subjects, trained in the use of the NADC lightbar and familiarized with unassisted positive pressure breathing, were exposed to +Gz accelerations on the NADC Dynamic Flight Simulator (DFS). Greyout thresholds were determined using the PALE seat, the NADC curved light bar and the NADC servo-controlled anti-G valve (SCAG). All combinations of the following independent

variables were systematically varied for each subject: two seat back angles (15 degrees upright and 60 degrees supine), two G onset profiles (GOR at 1G/15 sec. and ROR at haversine onset/offset durations of 3 seconds with a 15 second plateau), two anti-G pressurizations (no pressure or normal pressure), and two breathing techniques (with and without positive pressure breathing). During a daily exposure, there was one GOR profile to 5G upright or 7.5G supine and then three greyout thresholds at the ROR profile were determined for each of the remaining independent variables. All runs were made with the subjects relaxed and greyout thresholds were determined by incrementing the G plateau levels in 0.5G steps. Greyout thresholds and calculations for G tolerance have been described in a previous publication (3). Subjects were instrumented for electrocardiogram, ultrasound Doppler velocimetry, and blood pressure (inflated cuff). The breathing pressure supplied to the subject was monitored by a pressure transducer connected in the line to the oxygen mask. The subjects were dressed in standard NAVY flight gear. The HGU-33/P helmet assembly was used for these experiments and consisted of the PRK-37/P helmet, PRU-39A/P form-fit liner, and MBU-12/P oxygen mask.

A G compensated/pressure demand oxygen regulator was obtained from Clifton Precision, Instruments and Life Support Division (Davenport, Iowa). This regulator provided positive pressure as a function of +Gz. The actual control signal was pneumatic and derived from the anti-G suit line. The regulator outlet pressure was 1.8+/-3.6 mmHg until 3.5 PSIG anti-G valve pressure (3.3G) and then followed as a linear function of the anti-G valve pressure until 11 PSIG at which point the regulator output pressure was 60 mmHg. To use this regulator for unassisted positive pressure breathing, it was necessary to place three relief valves in line with the regulator output. These relief valves were set to vent pressures over 30 mmHg at a 95 lpm flow rate. The complete gondola configuration is shown in Figure 1. A combination of three-way valve position and selective application of power to the solenoid allowed for variation of the related independent variables.

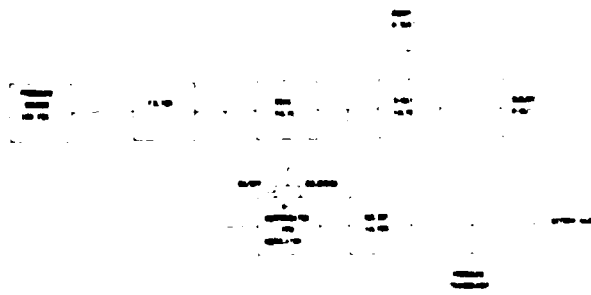


Figure 1

EXPERIMENTAL PROCEDURE

RESULTS: The response of the regulator to +Gz was as expected in the range tested. Figure 2 shows a subject response in the upright position to a gradual onset of acceleration to +5.5Gz. The pressure rose at approximately +4Gz to 7.5 mmHg and rose to a maximum of 18 mmHg at +5.5Gz. Figure 3 shows an upright rapid onset run to a lightbar endpoint. After attaining the plateau of +5.5Gz the in-line pressure rose to 20 mmHg within 0.8 seconds. The average peak pressure during the run was 19 mmHg.

During the supine exposures, the anti-G suit pressure was corrected for the seatback angle which resulted in lower suit and therefore lower regulator pressures (3). Figure 4 shows the results from a supine gradual onset exposure. The break-in point for positive pressure was at +5.2Gz to 8.0 mmHg and rose to 24.8 mmHg at +7.5Gz. These values are within specifications given the supine anti-G suit inflation schedule. Figure 5 shows the results from a supine rapid onset run to a lightbar endpoint. After reaching the +7.5Gz plateau the in-line pressure rose to an initial 18 mmHg within 0.4 seconds. The average peak pressure during this run was 22.5 mmHg.

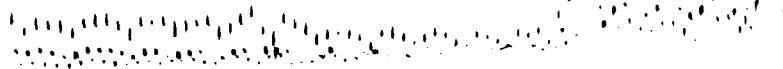
Figures 6 and 7 summarize the results for upright and supine rapid onset exposures respectively. These graphs represent subject in-line pressure data and regulator specifications versus +Gz levels. In Figure 6 the break-in point is shown to be +4Gz and there is good agreement between the maximum pressure points and the regulator specification line (solid) up to 21 mmHg where there was divergence due to the in-line relief valves. There was also a constant difference between maximum and minimum pressure up to 25 mmHg. Results for the supine position are shown in Figure 7. Here the break-in point was +5.5Gz. The maximum pressure points were consistently below the regulator specification line but were still

UPRIGHT

EKG



DOPPLER



30.0-
22.8-
15.0-
7.6-

PPB

GOR

2.0

+5.5Gz

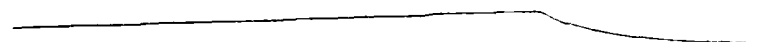


Figure 2 Upright Gradual Onset Run.

UPRIGHT

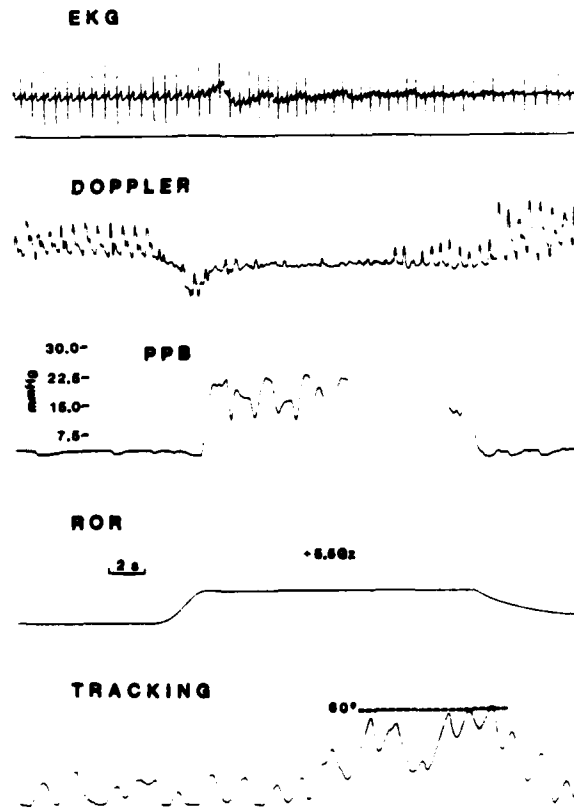


Figure 3 Upright Rapid Onset Run.

SUPINE

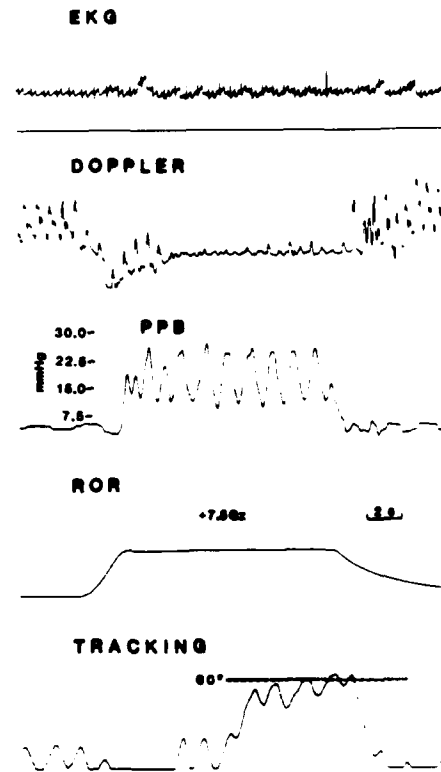


Figure 5 Supine Rapid Onset Run.

SUPINE

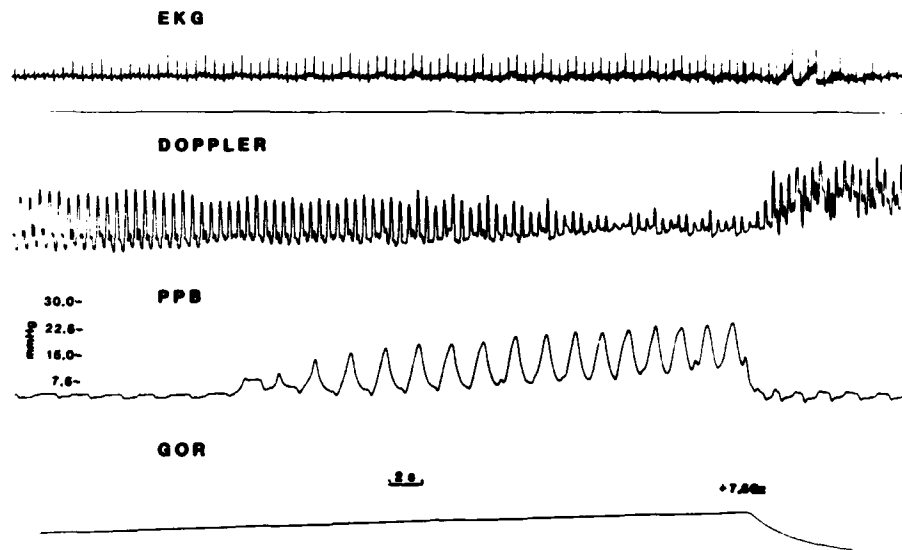


Figure 4 Supine Gradual Onset Run.

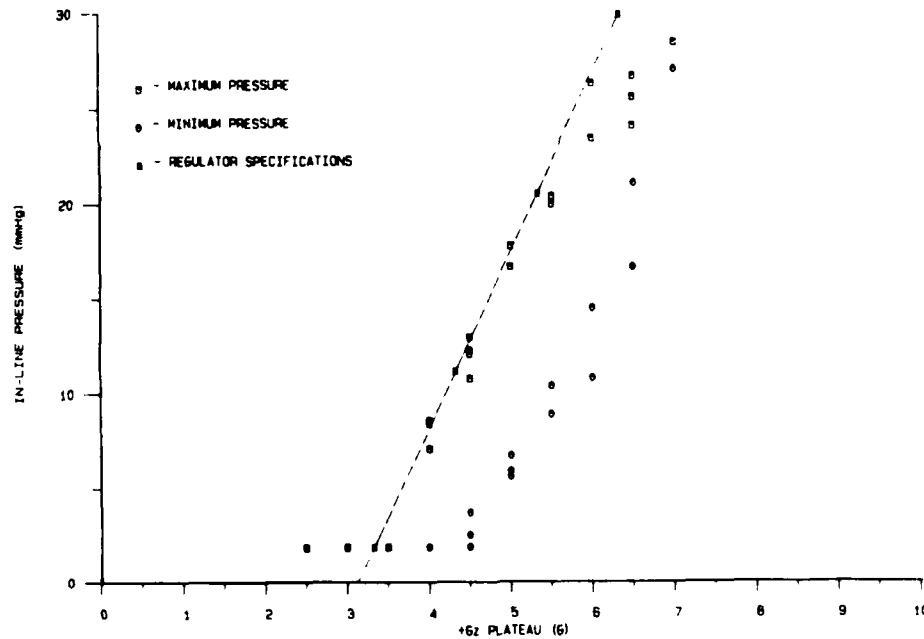


Figure 6 UPRIGHT IN-LINE PRESSURE VERSUS +6z PLATEAU

within the regulator error limits up to 20 mmHg. Divergence from the specification line is again due to the relief valves and a constant pressure difference is maintained up to 20 mmHg.

The in-line relief valves were essential to limit the regulator output pressure to 30 mmHg (unassisted positive pressure

breathing), but the relief valves also caused some artifactual results. Below the point where the relief valves open, an inspiration is indicated by a positive slope on the pressure curve and an expiration by a negative slope. After the relief valves open, a different mechanism occurs in which the mask pressurizes to the relief valve opening

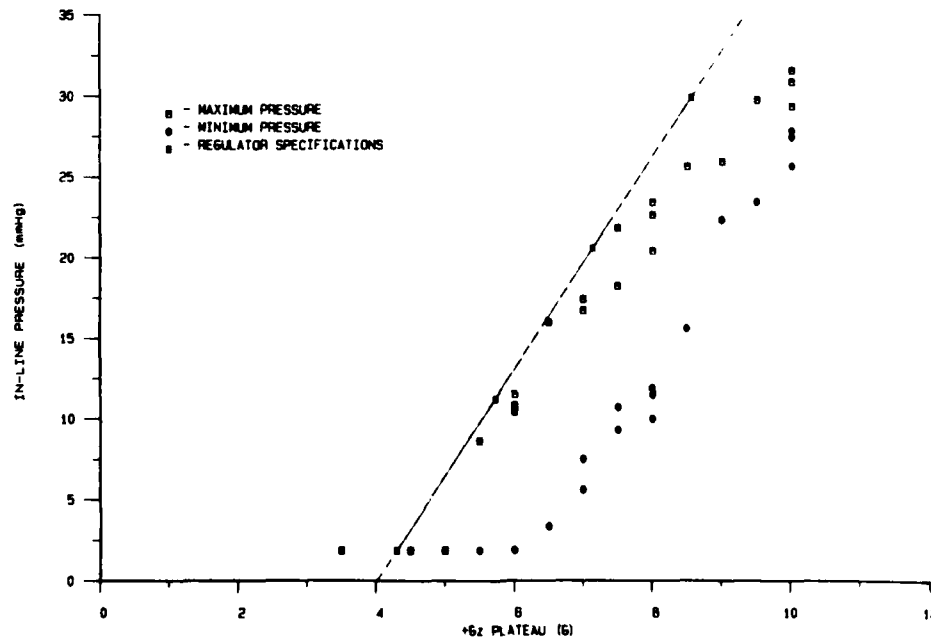


Figure 7 SUPINE IN-LINE PRESSURE VERSUS +6z PLATEAU

pressure. When an inspiration occurs the line pressure decreases (negative slope) and on expiration the pressure rises to the original value. The maximum pressure in either case is still accurate, but the characteristics have reversed.

Mean acceleration tolerance is shown in the bar graph of Figure 8. While upright versus supine and anti-G suit versus relaxed conditions were statistically different ($p < 0.005$) there were no statistically significant differences between any conditions that employed unassisted positive pressure breathing and its respective control (positive pressure alone versus relaxed and combined anti-G suit/positive pressure versus anti-G suit alone). However a plot of subject increased G tolerance versus in-line pressure, Figure 9, indicates that upright pressures greater than 27 mmHg and supine pressures greater than 20 mmHg gave individual increases in G tolerance greater than 0.5G.

DISCUSSION AND CONCLUSIONS: The G compensated/pressure demand oxygen regulator performed within specifications across the range of pressures investigated. When used with the NADC SCAG valve, the onset of the regulator pressure did not lag the anti-G suit pressure by more than the two seconds specified and typical values were less than one second. Divergence from the regulator output curve were due solely to the experimental requirement of pressure relief

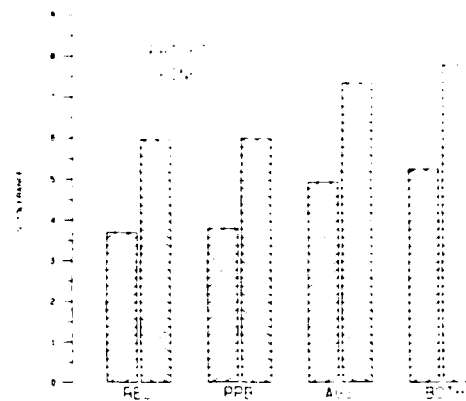


Figure 8 Comparison of Grand Means
By Condition.

valves. Incorporation of relief valves into the regulator output line introduces undesirable changes in pressure waveform character but has no effect on any maximum pressure measurements.

Subject response to unassisted positive pressure breathing was that it was much easier to breath in the supine position but not difficult in the upright position. There was also the unanimous response from subjects who experienced high G with high positive

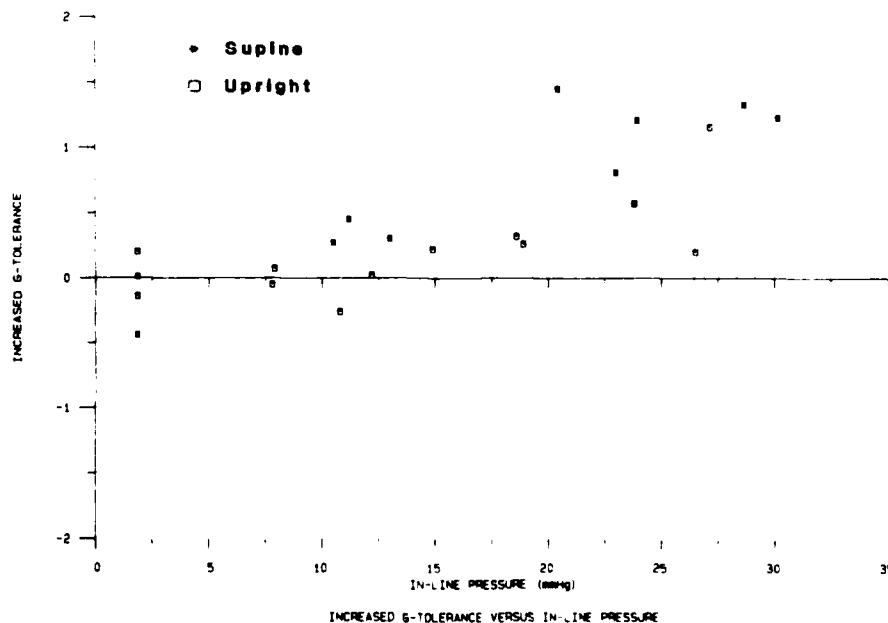


Figure 9

pressure that the regulator was not functioning on G offset. This response has been recorded before and is more related to the effects of breathing high positive pressure than any lack of regulator function (1).

The acceleration tolerance data obtained from this study indicate that unassisted positive pressure supplied with this schedule gives no increase in rapid onset acceleration tolerance. It is apparent from Figure 9 that the subjects who rode to higher +Gz levels received higher breathing pressures and that these higher pressures were more beneficial. With this pressure schedule, a subject's acceleration tolerance directly limited the maximum pressure that was supplied and some subjects reached their tolerance before the regulator supplied positive pressure. It is also apparent from Figure 9 that 20 mmHg supine and 25-30 mmHg upright were beneficial pressure levels. Future pressurization schedules for the rapid onset regime should take into consideration these minimum pressure values. In the unassisted mode of positive pressure breathing this may cause excessive fatigue but when coupled with counter-pressure assistance should be tolerated for much longer periods of time. The complete benefit of positive pressure breathing in the rapid onset regime has yet to be determined. Acceleration tolerance improvements beyond decreased breathing effort while supinated will be the subject of future research.

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BIOGRAPHY

Dr. Whitley is a member of the Acceleration Physiology Research Team of the Aircraft and Crew Systems Technology Directorate. Dr. Hrebien is head of that same team. Both received their training in Biomedical Engineering and are faculty members at Drexel University in Philadelphia, Pa.

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